

Presentation of an HF Radar
Development Program to the Eastern and Arctic
Petroleum Operators Associations

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by

K. A. Butt
E.M. Reimer

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C-CORE

CENTRE FOR COLD OCEAN RESOURCES ENGINEERING
MEMORIAL UNIVERSITY OF NEWFOUNDLAND
ST. JOHN'S, NEWFOUNDLAND, A1B3X5 CANADA
TELEPHONE (709) 737-8364

INTRODUCTION

Recently a new remote sensing system called Coastal Ocean Dynamics Applications Radar (CODAR) has been developed for measuring ocean surface currents through Doppler processing of the high frequency (HF) surface wave radar signal backscatter from the ocean surface. Although CODAR has been primarily a National Oceanic Atmospheric Administration (NOAA) development, the overall work on this technique to date has taken place in many international government laboratories and universities (Barrick et al, 1977; Trizna et al, 1977; Shearman et al, 1979; SRI International, 1980).

Now, C-CORE through its commitment to the development of Canadian cold ocean resources has recently initiated a program to acquire CODAR technology with the intention of developing it further to meet Canada's needs.

The operational capability of CODAR is spatial mapping of ocean surface current vectors and repetitive mapping in a temporal sense. This is a unique capability which is not available through any of the conventional oceanographic techniques. A short list of potential applications are (i) routine environmental measurements to quantify coastal processes, (ii) the ability to directly monitor surface transport in the case of an oil spill accident, (iii) a potential tool to study ice and iceberg behaviour and (iv) support to search and rescue.

This paper presents a brief overview of the state-of-the-art and outlines a technology transfer package for industry. An application scenario is presented for the Labrador coast but is equally applicable to Beaufort Sea operations. Although work should be performed in both these

areas, the initial thrust will have to be concentrated in that area receiving majority financial support.

CODAR FOR OCEANOGRAPHIC MEASUREMENT

HF radar (CODAR) utilizes the 6 metre ocean wavelength which is one-half the electrical wavelength of the transmitted signal as a resonant structure satisfying the Bragg (first order) equation for scattering (Crombie, 1955). For any given ocean wavelength, the phase velocity of the approaching and receding wave can be analytically determined. Since Doppler frequency shift is a measure of velocity, it therefore can be shown that the Doppler frequency of the first order sea echo response is a measure of the phase velocity of the 6 metre ocean wave. We also know the transmitted wavelength, therefore we can calculate the expected Doppler response of the first order backscatter and thus assume that any difference in the measured first-order Doppler response is a measure of the near-surface currents running radial to the radar antenna. The resulting mathematical equation describing the velocity of the radial surface current component is given by:

$$V_r = \frac{C}{2f_0} (f_A^{(+)} - f_E^{(+)})$$

where V_r = radial current velocity in metres/sec.

C = free space EM propagation velocity in metres/sec.

f_0 = radar frequency in Hertz

$f_A^{(+)}$ = positive component* of the actual Doppler frequency shift of the radial received signal in Hertz

$f_E^{(+)}$ = positive component* of the expected Doppler frequency shift due to 1st order Bragg diffraction in Hertz

* In practice, f_A & f_E are derived from an average of both the positive and negative components of the complex Doppler spectrum.

A more complete discussion of this relationship is given by Barrick et. al. (1977) where $(f_A^{(+)} - f_E^{(+)})$ is given as Δf .

The ease with which this measurement can be made through surface wave propagation is in direct contrast to similar techniques utilizing the ionosphere for extended range through reflection/refraction where the backscatter Doppler information has been contaminated by uncertain ionospheric movements.

The 25 MHz frequency used by CODAR is a tradeoff of the lower surface wave attenuation available at lower frequencies for the equipment portability afforded by shorter wavelengths. This tradeoff is not as severe as one might first think. The longer ocean waves needed to satisfy the Bragg resonant backscatter condition often have smaller amplitudes and hence scatter less radar energy thus reducing effective range. The shorter ocean wavelengths (in this case, 6 m) are present most of the time and can be fully developed in water depths greater than 2 metres. This also means that currents are measured over the first metre of water depth indicating true "surface" movement.

One radar station can only measure the component of the total velocity vector that is either directly toward or directly away from the radar. Two radars that are physically separated are required to obtain the complete vector. The two components of the vector are combined using vector addition in one of the last steps in the data interpretation software of a high speed computer system. When the radar data is interpreted in the field the vector information from one site is transferred to the other site automatically by

use of a VHF telemetry link. The complete current vector map can then be drawn on a high speed incremental plotter in the field or stored for later analysis.

The following briefly lists the present capabilities of a CODAR current mapping radar:

Map resolution	- 1.2 km X 1.2 km
Approximate map size	- 60 km X 60 km
Maximum range	- 76 km
Demonstrated range	- 60 km
Maximum velocity	- Greater than 3 m/sec
Measurements proved possible	- Wind driven surface currents over 36 minute average to ± 10 cm/sec.

The theoretical limits of the present system based upon a 8192 point time series yields current velocity measurements to ± 0.6 cm/sec. The hardware noise limits indicate measurement capabilities to 0.1 cm/sec. However, it is not reasonable to assume that the currents have remained stable over the 36 minutes necessary to collect the complete time series. In drifter comparison experiments the accuracy has been better than ± 10 cm/sec. However, it should be noted that this error could be a reflection of uncertainties in drifter motion.

A summary of CODAR system characteristics is presented in Table 1.

CODAR APPLICATION SCENARIO

A significant proportion of the environmental baseline work carried out in relation to offshore exploration is done specifically as preparation in case of an oilspill or blowout. Because of its unique ability to sense and map wind driven surface currents over a large area, CODAR is ideally suited to both historical scenario preparation and for operational trajectory sensing in the case of an actual spill.

At present, procedures in preparing scenarios for EIS hearings are based on the use of models which infer surface drift on the basis of measured winds, currents and drogue or drifter trajectories. The geographical areas covered are generally very large and the quantity of hard data very small even in well studied areas such as the Scotian shelf. Although most operators carry out extensive oceanographic programs in conjunction with drilling operations, the dimensions of Canada's coastlines are vast in relation to the scientific and industrial oceanographic effort which the country can support. Standard oceanographic methods are expensive, local and not well suited to the measurement of wind driven surface currents.

CODAR will not solve all of the shortcomings of conventional techniques but it could represent a quantum improvement in dealing with coastal circulation monitoring and modelling over large geographical areas. The system could usefully be brought to bear in the Beaufort Sea, Lancaster Sound and Labrador Shelf areas. We have outlined a typical application methodology for the Labrador Shelf in the ensuing scenario.

Hard oceanographic data from the Labrador Shelf has been almost non-existent until the recent surge of interest in petroleum exploration. Indisputably, the general current direction is southward along the coast but very little is actually known of the details of that ocean current.

The accumulating results from recent drifter studies (Fig. 1) carried

out by C-CORE suggest that there is a distinctive nearshore flow which hugs the coastline but that entry into this flow becomes unlikely south of about 58°N latitude. Of the several thousand surface drifters released on the Grand Banks, none have yet been recovered in Newfoundland or other areas of the Canadian coast.

Management of an oilspill countermeasures operation in this region therefore would not appear to require a detailed knowledge of offshore circulation as so much as a knowledge of the coastal circulation patterns from which oil, once entrained in the nearshore flow would be likely to reach shorelines.

A two stage approach would be appropriate: 1) to establish (by measurement) a detailed model of coastal circulation patterns, and 2) use the CODAR operationally to map local spill trajectories and to derive a larger model of coastal circulation.

The first stage would entail an extensive data collection operation. Surface circulation (CODAR), wind and preferably deep current information would be collected at selected locations along the coast for a minimum of several tidal cycles at each site (Fig. 2). This accumulated data could then be built into a coastal circulation model.

In the event of a spill the radar system could be located downstream at a likely landfall area where it could provide detailed trajectory information for anything within a 60 km radius. Further, the collected surface current information could be projected through the established coastal circulation model (Fig. 3) to provide reasonably accurate surface information on much larger coastal and offshore circulation patterns. (This modelling function could conceivably be operated on the high capacity minicomputer which is built into the CODAR system).

Although modelling has been extensively used for scenario preparation, it has never been seen as a reliable operational tool because of its critical dependence on hard data. The CODAR system would very effectively provide this essential component in the monitoring and tracking of an oilspill.

TECHNOLOGY TRANSFER PROGRAM

The potential of HF radar for the remote measurement of coastal and offshore sea state and surface currents has been clearly demonstrated by CODAR. A list of applied operations is presented in Table 2. It is our belief that CODAR is a stepping stone to a technology that may hold the key to reliable ice hazard detection and tracking for offshore exploration and Arctic transportation. However, before we proceed too far down any potential avenues of application, it is important that we fully understand the existing limits of this technology. A technology transfer program is thus a logical first step to further development. Appendix A illustrates the history of remote sensing at C-CORE and provides some projection of future efforts.

It is the intention of C-CORE to initially focus the energy and resources necessary to acquire a state-of-the-art CODAR system. A work schedule is presented in Figure 4. The bulk of the feasibility function indicated with the dotted line has already been completed and is reported by Butt and Jeans (1981).

Please take note of the activity in Figure 4 labeled "Establish Analytical Program To Guide Ice Radar Development". This item has replaced an originally proposed iceberg monitoring field program. In view of the large expense that would have been incurred for just one empirical study over one ice type the program has instead been modified to include a broader analytical approach to the entire problem of ice hazard detection involving all ice types. The program will primarily involve researchers already engaged in radio propagation and scattering studies at Memorial University of Newfoundland and will not interfere with the transfer program at C-CORE. However, plans for effective use of CODAR technology in empirically assisting this study are nearing completion. Cooperation between C-CORE researchers and Memorial faculty is con-

tinuing to grow and is expected to form a healthy research atmosphere unique to Canada.

A key prerequisite to any technology transfer project is access to the technology. NOAA has spent over 25 man-years developing the present state-of-the-art computer software for surface current mapping and another considerable amount of time on hardware engineering. Despite the high cost of this effort NOAA has provided significant portions of their software to C-CORE for evaluation at no cost with the understanding that in the event that industrial support is established, then the appropriate terms of remuneration will be discussed. To further assist in the technology transfer, a company headed by the original CODAR program manager, Mike Evans, has spun off from NOAA. Called CODAR Technology Inc. (CTI), the company's mandate is to provide consultation and design services for HF radar applications. Appendix B describes this in more detail. C-CORE has already entered into contract arrangements with CTI although for the most part most information flowing over the U.S. border has so far been at no cost. It is anticipated by both parties involved (i.e. C-CORE and CTI) that any Canadian development towards ice hazard detection will be of benefit to the U.S. as well.

Recently a seminar was held by C-CORE and the Ocean Engineering group at Memorial University of Newfoundland on the topic of HF surface and skywave radar systems. The speakers were Dr. Don Barrick and Dr. Tom Georges of NOAA and Mr. Mike Evans of CTI. Representatives of the Newfoundland Government, Canadian Coast Guard, Atlantic oceanographic research community, local academic community and local industry were present for the two hour presentation. Most questions regularly asked by all those interested in CODAR

applications were answered after the seminar by Don Barrick and Mike Evans. A complete verbatim transcript of the seminar is available from C-CORE.

Although the paper deals primarily with the concepts of surface wave propagating HF radar, it is important to note the presence of skywave Over-The-Horizon (OTH) radar research in Canada (Butt et.al., 1981). This technique attributes its name to the fact that the radio waves are transmitted beyond the horizon by "bouncing" the signal off an ionized layer of the Earth's atmosphere called the ionosphere. Subsequent to reflection from the ocean surface, the signal is returned to the source via the same ionospheric path. The backscattered signal has been shaped by the ocean's surface and through careful mathematical interpretation the ocean signature can be extracted.

Recently C-CORE began participating with the Communications Research Centre (CRC) in Ottawa in a program to establish the feasibility of applying the latest developments of this technology to the Canadian east coast conditions. Supported primarily with Department of Fisheries and Oceans (DFO) funding, C-CORE has undertaken the responsibility of interpreting the first results using the classical techniques developed by other groups in the U.K. and the U.S.A. Some of these techniques are briefly described by Dr. Tom Georges of NOAA in the "Verbatim Transcript of C-CORE HF Radar Seminar at Memorial University of Newfoundland".

FUTURE DEVELOPMENT

Close to the Canadian interest, though many basic questions are yet unanswered, is the potential of this type of radar system to detect ice conditions or iceberg targets. This latter conjecture is based on the fact that the signal return from an iceberg or ice cover at the sample cell could not undergo the Bragg scattering which results from the diffraction grating caused by wave patterns of an open sea. In fact, an ice covered ocean would be expected to act as a smooth plane target to the transmitted beam and detection would result from the absence of the wave induced Doppler shift. Conversely, the radar cross section, RCS, of an iceberg at HF can be described basically as a hole in the ocean where the edge of the hole could be expected to act as a corner reflector thus increasing the strength of return for that cell only and possibly yield detection.

Further examination of the "hole" concept gives rise to the suggestion of application to an entire ice field. The electrical properties of first year sea ice and that of older consolidated ice floes and ridges differ considerably. It is expected that at HF, surface propagation over first year sea ice (ie: high conductivity) would be relatively uniform. However, if sharp impedance discontinuities such as a severe drop in average conductivity over an effective wavelength were encountered it is conceivable that energy will be reflected at the boundary mismatch. Although resolution at HF would not be high as compared to conventional microwave imaging radars, it maybe sufficient to image those obstacles deemed hazardous to shipping.

Recently C-CORE and Ocean Engineering at Memorial University have taken positive steps towards establishing a comprehensive empirical and analytical

program to evaluate this potential. Graduate studies have been initiated under the supervision of Dr. John Walsh and a recent application to the National Science and Engineering Research Council (NSERC) of Canada has been filed under the Strategic category of importance for hopes of assistance to the costly field work described.

The potential of using HF Radar as a tool to study iceberg behaviour is very exciting. The threat of an iceberg collision with offshore platforms is, at the moment, a major concern for offshore development on Canada's East Coast. The question of forces on impact, maximum iceberg size to expect, and possible countermeasures activity are open to much debate; a debate which will not be effectively resolved until there is more detailed knowledge on sighting statistics and of the natural forces that cause iceberg motion. The HF Radar alone, or in the initial phase, when system truthing is necessary, HF Radar in conjunction with a PPI marine radar, could track both the iceberg movement and the surface current of the water mass transporting the iceberg. This ability to track the surface current in a spatial or Lagrangian sense is in contrast to past work where the only current description to support iceberg dynamics were single point moorings normally spatially separated from the iceberg. Data available on iceberg tracks suggest ocean current vectors vary radically over short horizontal distances and a current at one point may not describe the current field a kilometre away due to lack of coherence within the field. This in turn can ultimately provide the knowledge base to plan more effective countermeasures schemes and provide a measurement tool to support iceberg drift forecast models.

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Table 1

CODAR

- **Portable HF Doppler radar** (12 metre wave length).
- **Ocean surface currents** to 1 metre depth (6 metre wave).
- **Large areal coverage** allows continuous trajectory prediction (60 km range).
- **Accuracy** between 0.1 and 10 cm/sec with 1 km resolution.
- **Two sites** required for complete vector plotting (telemetry or mag. tape).

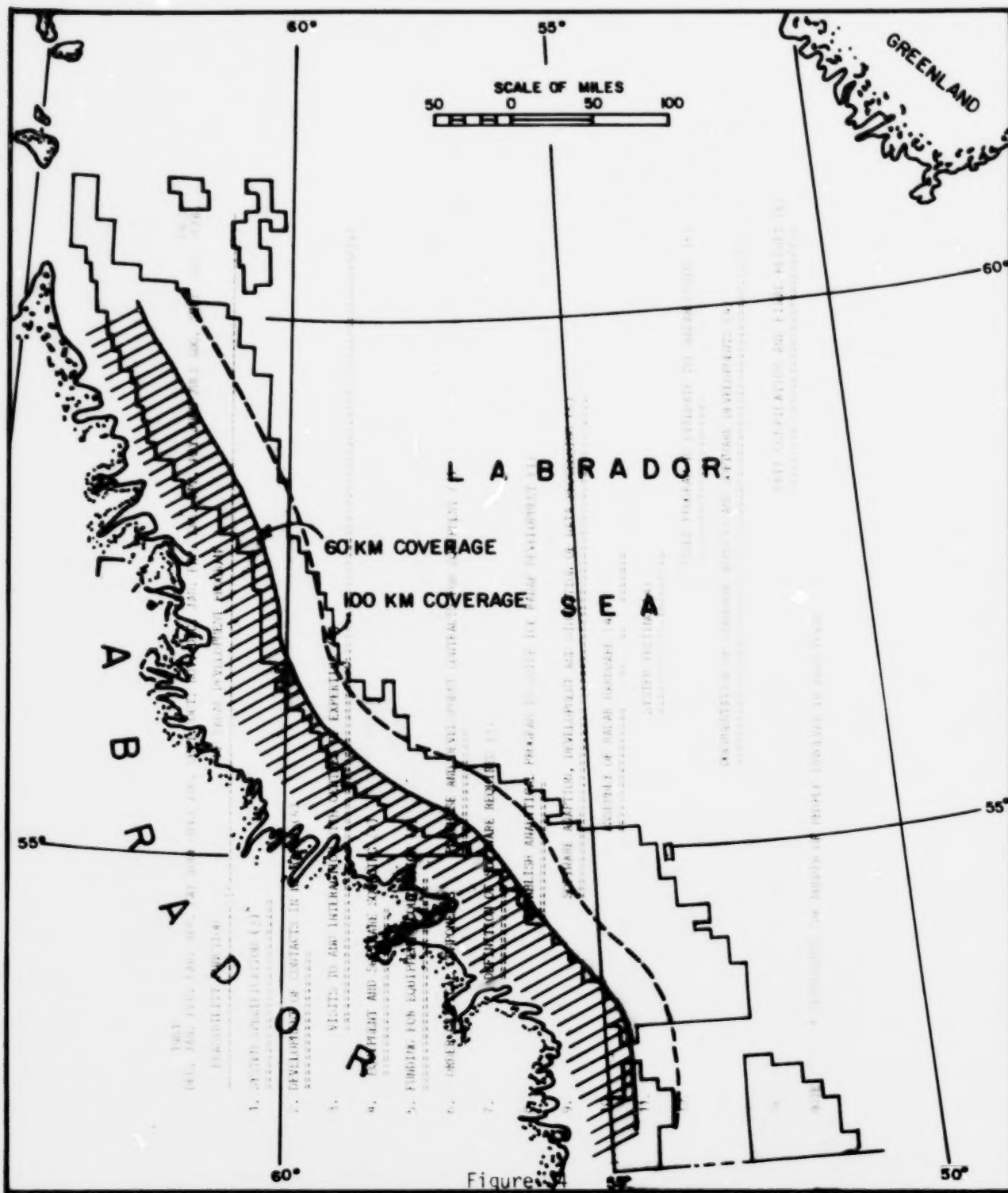
Table 2

Summary of Applied Operations of CODAR

1976	—	Gulf-stream currents off Florida.
1977	—	Complex surface currents in Cook Inlet, Alaska. (CODAR film)
1978	—	Complex outflow of the Savannah River, Georgia.
1978-9	—	Complex surface current flow with tidal analysis of Puget Sound, Washington.
1979	—	MARSEN* Experiment, North Sea.
1980	—	ARSLOE† (wave directional spectra), Duck, North Carolina.

* — MARSEN — Maritime Remote Sensing Project

† — ARSLOE — Atlantic Remote Sensing Land Ocean Experiment.



LABRADOR COASTAL MAPPING POTENTIAL

Figure 2

TYPICAL CODAR APPLICATION SCENARIO

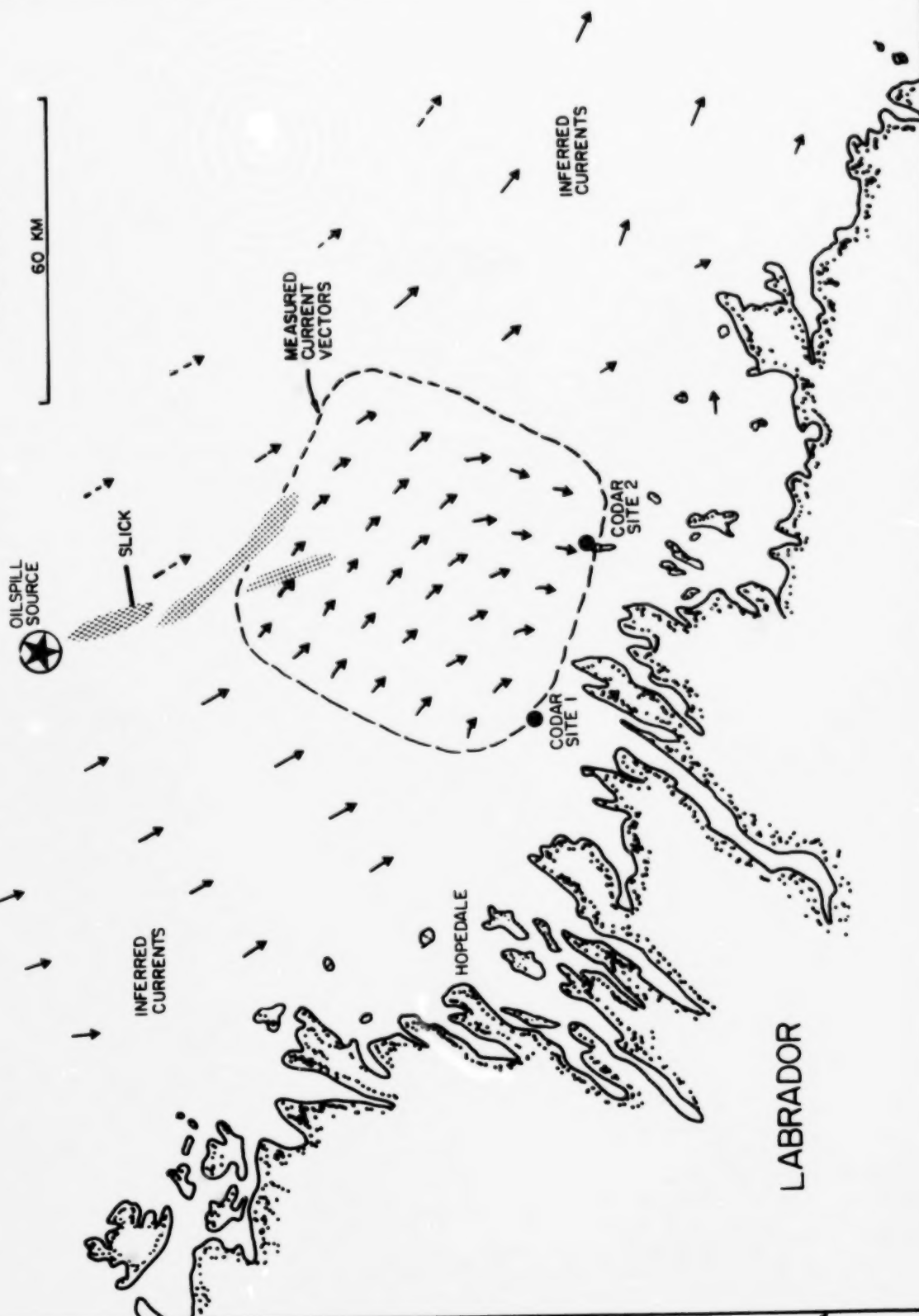


Figure 3

1983	1982
DEC. JAN. FEB. MAR. APR. MAY JUNE JULY AUG. SEPT. OCT. NOV. DEC. JAN. FEB. MAR. APR. MAY JUNE JULY AUG. SEPT. OCT. NOV. DEC.	
FEASIBILITY FUNCTION	OF RADAR DEVELOPMENT PROGRAM
1. SYSTEM SPECIFICATION (2) *	
2. DEVELOPMENT OF CONTRACTS IN OF RADAR (4)	
3. VISITS TO AND INTERACTION WITH CENTRES OF EXPERTISE (4)	
4. EQUIPMENT AND SOFTWARE SOURCING (4)	
5. FUNDING FOR EQUIPMENT ACQUISITION (3)	
6. ORDER CRITICAL COMPONENTS PURCHASE AND DEVELOPMENT CONTRACTS FOR EQUIPMENT (4)	
7. DEFINITION OF SOFTWARE REQUIRED (3)	
8. ESTABLISH ANALYTICAL PROGRAM TO GUIDE ICE RADAR DEVELOPMENT (1)	
9. SOFTWARE ADAPTION, DEVELOPMENT AND SIMULATION OF DATA PROCESSING (5)	
10. ASSEMBLY OF RADAR HARDWARE (4)	
11. SYSTEM TESTING (4)	
12. FIELD PROGRAM TO EVALUATE THE RADAR SYSTEM (6)	
13. DOCUMENTATION OF HARDWARE ASPECTS AND SOFTWARE DEVELOPMENTS (4)	
14. DATA COMPILED AND FINAL REPORT (6)	
NOTE ... * REPRESENTS THE NUMBER OF PEOPLE INVOLVED IN EACH PHASE.	

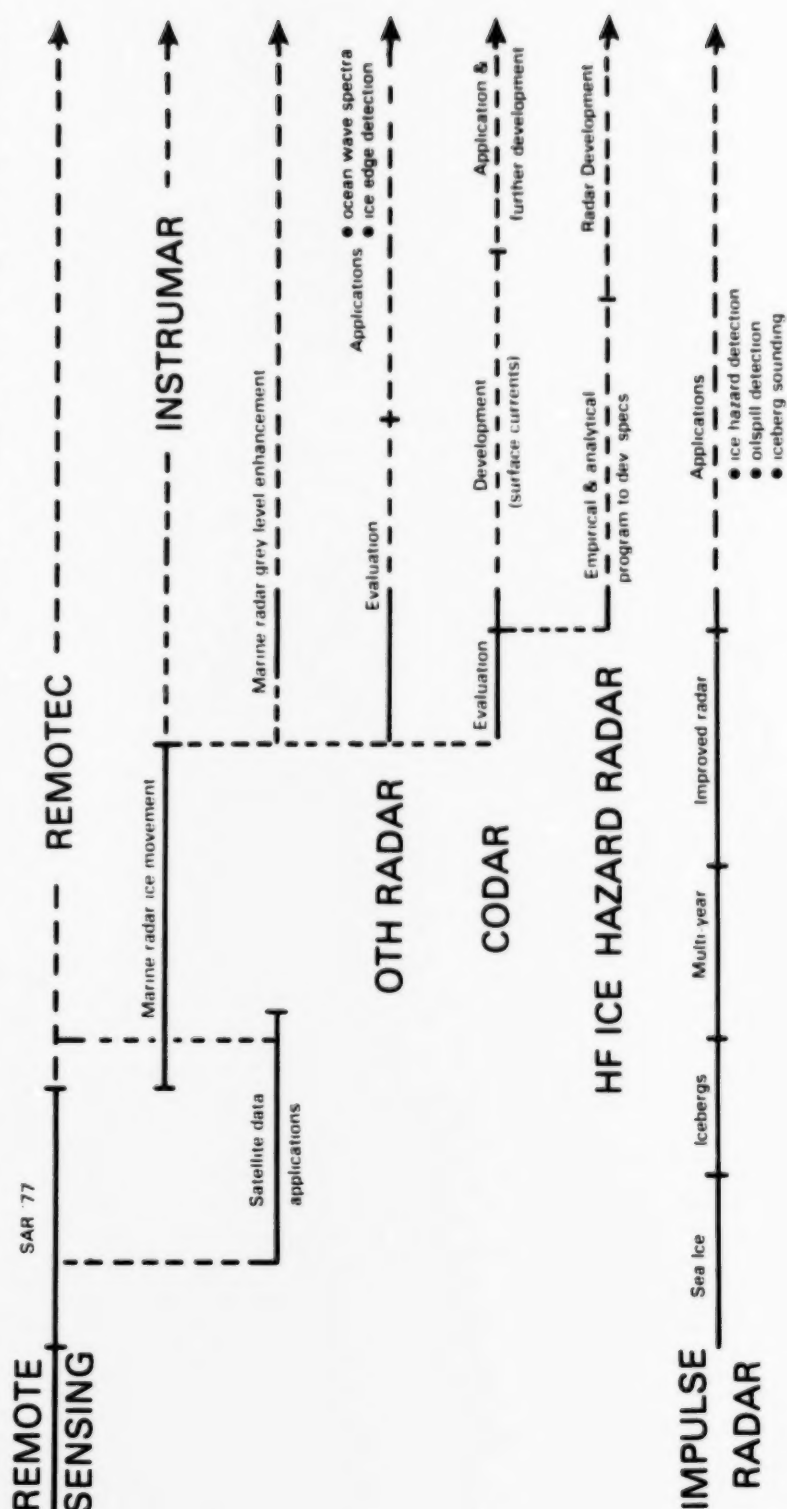
Figure 4

Appendix A

C-CORE Radar Programs

1976	1977	1978	1979	1980	1981	1982	1983	1984
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C-CORE RADAR PROGRAMS



Appendix B

CODAR Technology Inc.



CODAR TECHNOLOGY, INC.

1428 Florida Ave.
Longmont, Colorado 80501

(303) 778-0472

CTI . . . AN INTRODUCTION

Codar Technology, Inc. is a problem-solving company specializing in ocean remote-sensing and related technology. We provide engineering design and consulting services for HF radar applications and supply high-quality, reliable systems to government agencies and the petroleum industry. At present, we are providing services to the U.S. Government, West Germany, Canada, and several major oil companies.

Our name is derived from CODAR -- Coastal Ocean Dynamics Radar -- a new ocean remote-sensing tool developed by the Wave Propagation Laboratory of the National Oceanic and Atmospheric Administration. From compact, portable shore stations, CODAR maps surface currents and wave conditions over thousands of square kilometers of sea, providing many times the information available from previous instruments. The response to the CODAR concept from the international oceanographic community has been so enthusiastic that we expect CODAR-derived instruments to revolutionize ocean-surface measurements of currents, wave directional spectra and winds over the next decade.

CTI was formed in 1980 by Michael W. Evans, the co-inventor of CODAR and manager of NOAA's CODAR program since its beginning in 1975. We are developing a commercial market for CODAR-related systems as well as providing research and services in support of their scientific applications. Specific projects now under way include:

- An HF Doppler transponder system for accurately tracking the velocity of ice and ocean currents.
- Second generation CODAR systems in support of U.S. and foreign research programs.
- Extension of CODAR measurement capabilities to include directional ocean-wave spectra.
- Development of a CODAR system for use on offshore oil production platforms.
- Data acquisition systems in support of the petroleum industry and government research programs.

Recognizing that few ocean remote-sensing problems can be solved within the confines of a single discipline, CTI has assembled a unique cross-disciplinary team of consultants and senior staff with expertise in the following areas:

- Radar systems engineering
- Digital/analog signal processing
- Digital hardware/software engineering
- Mathematical theory of radar interaction with the sea
- Data analysis and interpretation
- Field engineering
- Oceanography

To meet short-term customer requirements efficiently, CTI utilizes outside contractors and consultants, who provide research, design and manufacturing services on a demand basis. We also maintain well-equipped engineering and computer facilities. Please contact Codar Technology with your ocean remote-sensing problems.

APPENDIX C

FUNDING FOR CODAR CURRENT MAPPING SYSTEM

FUNDING FOR CODAR CURRENT MAPPING SYSTEM

Program costs fall into the two distinct categories of equipment acquisition and development.

C-CORE's original proposal to Supply and Services Canada (DSS) deliberately emphasized this separation in hopes of generating a dual funding program where government would support development and industry would acquire the equipment.

Although, having taken longer than expected, this scheme has been achieved at least in part with some government funding for the feasibility stage. Transport Canada has indicated support covering the first year of development.

All of the hardware for a CODAR current mapping system is commercially available and some components such as the transmit/receive antennas, the antenna multiplexer and VHF data link can be assembled in house using Canadian built parts wherever possible. All of the computer equipment can be purchased in Canada with exception of the Signal Processing Interface (SPI). Due to very limited demand for both the SPI and HF receiver they are at present only available from a single supplier in Boulder. Hopefully as the technology transfer nears completion the Canadian radio electronics industry will be in a position to respond to future developments. All efforts will be made to ensure that this opportunity to "catch up" is not wasted. Of particular importance will be the opportunity to direct the development towards specific problems unique only to Canadian waters.

One CODAR radar site will be purchased in any event for C-CORE's ice radar research program in order to prevent delay. Major processing hardware for one site has already been supplied through DSS bridge funding to Fisheries and Oceans. If the emphasis remains on current mapping for the first instance, then additional computer hardware will be necessary.

Meanwhile existing equipment is also finding application to C-CORE's skywave radar project (Butt et.al., 1981) with the Communications Research Centre in Ottawa.

An estimate of the funds needed for the development program are summarized as follows:

	to March 1982	to March 1983
Labour -	\$ 79,300.00	\$ 63,300.00
Materials -	9,400.00	6,900.00
Subcontracts -	10,700.00	4,800.00
Direct Costs -	12,200.00	55,500.00
Travel and living -	7,800.00	6,900.00
Overheads -	<u>24,900.00</u>	<u>19,600.00</u>
	\$144,300.00	\$157,000.00

Total development costs are \$301,300.00

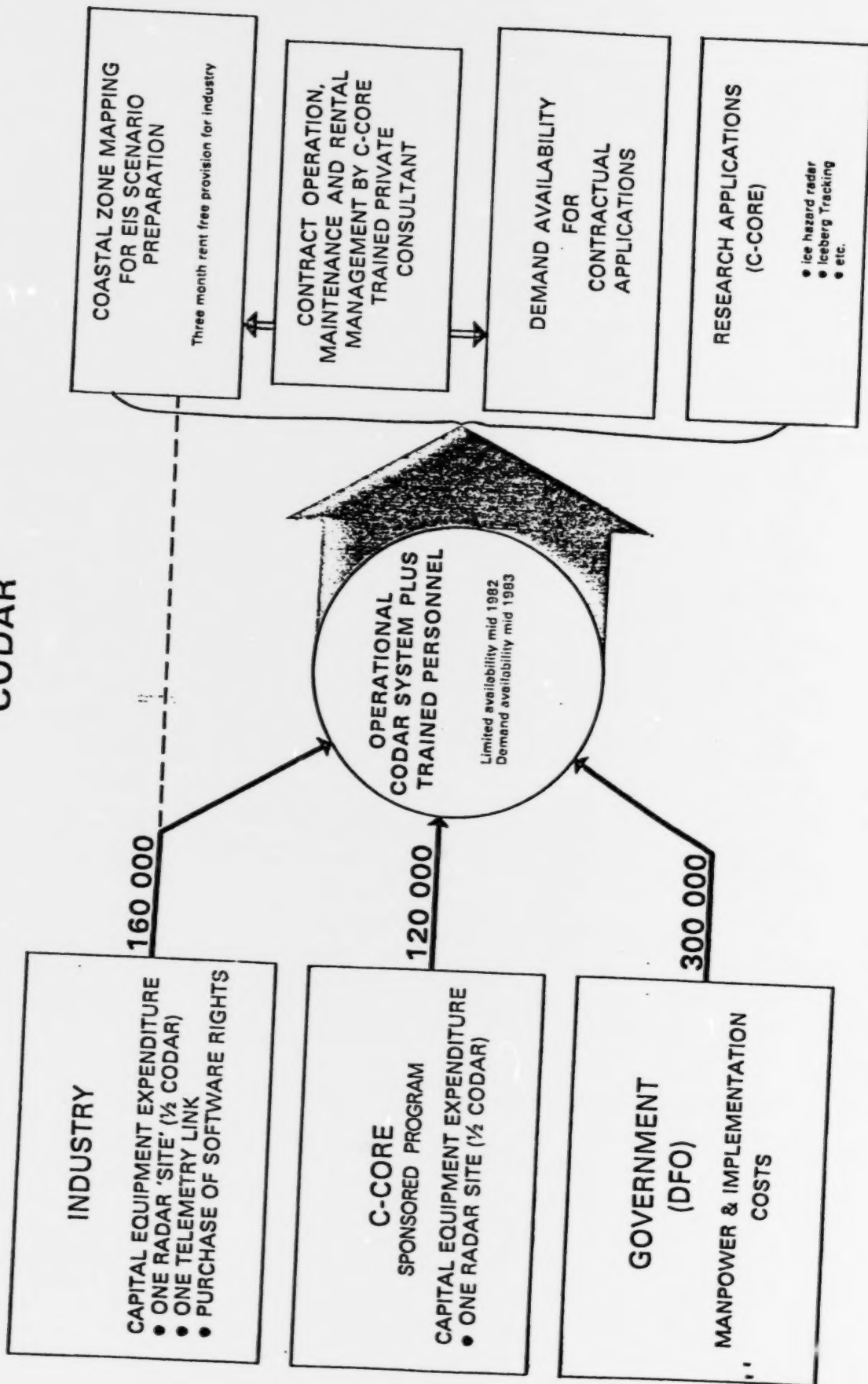
The following is a detailed cost component breakdown for a complete "one site" CODAR system including VHF data telemetry link and access to NOAA software.

1	PDP 11/23 minicomputer system	\$36,100
1	SPI board (CODAR Tech. Inc. (C.T.I.))	6,000
1	Video interface board (C.T.I.) and display	3,600
1	CODAR (non-volatile) memory (C.T.I.)	1,200
1	Filter/crystal set (C.T.I.)	1,920
1	HF receiver (C.T.I.)	35,000
1	HF transmitter (10 kw)	12,000
1	VHF telemetry system	12,000
1	Transmitting antennas (HF)	2,000
1	Receiving antennas and multiplexer (HF)	4,200
4	ECS containers	8,000
1	CODAR transponder	3,600
1	CODAR software package	30,000
		<u>\$155,620</u>

Note that U.S. prices in the above cost breakdown have been prorated to Canadian dollars based on a 20% exchange rate, miscellaneous costs are included under the related item listings and FST, Duty and Provincial sales tax have been excluded.

Acquisition of this equipment by industry and applied in combination with the hardware acquired for C-CORE's ice radar research program would complete the two site CODAR system needed for "full vector" surface current mapping. A summary of the cost sharing program is shown in the attached figure.

CODAR



POOR

QUALITY

ORIGINAL

